Effects of Swine Lagoon Effluent Relative to Commercial Fertilizer Applications on Warm-Season Forage Nutritive Value

A. Adeli,* J. J. Varco, K. R. Sistani, and D. E. Rowe

ABSTRACT

Two field experiments were conducted to evaluate the effects of comparable rates of swine lagoon effluent and commercial fertilizer at different harvest dates on dry matter yield and nutritive value of bermudagrass (*Cynodon dactylon* L.) grown on an acid Vaiden silty clay (very fine, montmorillonitic, thermic, Vertic Hapludalf) and johnsongrass (*Sorghum halepense* L.) grown on an alkaline Okolona silty clay (fine, montmorillonitic, therimic, Typic Chromudert). At each site, a randomized complete block design with a factorial arrangement of treatments replicated four times was used. Treatments were multiple effluent irrigations resulting in four N rates from 0 to 665 kg N ha^{-1} yr^{-1}. In each block, commercial fertilizer (N, P, and K) treatments were applied to additional plots at rates equivalent to swine effluent rates. Total dry matter yield and crude protein (CP) for bermudagrass and johnsongrass reached a plateau with application of approximately 450 kg N ha^{-1} from either swine effluent or commercial fertilizer. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) peaked at the low fertilization rate and then declined with increasing effluent and commercial fertilizer rates. An inverse relationship was obtained for in vitro true digestibility (IVTD) in response to fertilization rate for both grasses. Forage dry matter, CP, NDF, and ADF levels peaked in the July harvest and then declined, but forage IVTD level declined in July harvest. Only in July 1996, forage NO_3–N concentration was lower for swine effluent than commercial fertilizer. Swine effluent and commercial fertilizer had similar effects on forage dry matter yield and nutritive value.

Animal waste application to pasture and crop lands can be an effective method of recycling nutrients while contributing to the concept of sustainable agriculture. With increasing demands on the livestock industry for efficient animal production, it is important to consider the nutritional values of forages treated with animal wastes.

There has been considerable research on the impact of animal waste on the environment, soil and plant nutrient levels, and dry matter yield production. Previous research with warm-season grasses has shown animal waste and N fertilization to increase forage growth (Harvey et al., 1996; Caraballo et al., 1997) with peak dry matter production for warm-season grasses during midsummer (Chambliss et al., 1999; Mislevy, 1999). Although N fertilization to warm-season grasses increases dry matter yield, animal production is often depressed, and this depression is related to decreased forage quality (Sollenberger et al., 1989; Rusland et al., 1988). Inconsistent results have been reported on the effects of animal waste on forage nutritive value, including CP, fiber contents, and digestibility. For example, Min et al. (2002) reported that application of dairy slurry to forage grasses at rates of 410, 690, 830, and 970 kg N ha^{-1} increased CP concentration compared with the control treatment, but ADF and NDF were not affected. In another study, Harvey et al. (1996) reported that CP concentration of bermudagrass increased only slightly when N rate from swine effluent application was increased from 456 to 873 kg ha^{-1}. Johnson et al. (2001) reported that NDF and ADF concentration of bermudagrass increased quadratically with increasing N fertilization, but an inverse relationship was observed for grass digestibility. Other researchers reported that increased N fertilization had little to no effect on NDF concentrations in timothygrass [*Setaria sphacelata* (Schumach.) Stapf & C.E. Hubb.] and bermudagrass, respectively (Anderson et al., 1993; Rogers et al., 1996).

Nitrogen is the primary element on which waste application rates have been based. Concentrations of NO_3–N in forages may accumulate and reach toxic levels if animal waste is applied in excess (Bergareche and Simon, 1989). Nitrate toxicity as a result of waste application has been reported, and much attention has been given to the nitrate content of forage crops (Fontenot et al., 1989). This is partly because nitrate poisoning can result from feeding high-intake-rate materials to livestock (Veen and Kleinendorst, 1985). Additionally, the presence of very low nitrate concentrations may suggest that higher yields could have been obtained by applying more N to forage (Wilman and Wright, 1986). Applications of anaerobic swine effluent to a temperate forage mixture to provide 600 and 1200 kg N ha^{-1} resulted in forage NO_3–N concentrations of 1.5 and 2.7 g kg^{-1}, respectively (Burns et al., 1987). Burns et al. (1985) irrigated 'Coastal' bermudagrass with swine effluent at rates equivalent to 335, 670, and 1340 kg N ha^{-1} and found that the 1340 kg N ha^{-1} rate increased forage nitrate concentration to 2.71 g kg^{-1}, which was below the potentially toxic level of 3 g kg^{-1} for ruminants (Harvey et al., 1996).

Considerable research has investigated the impact of animal waste such as swine effluent (Burns et al., 1990; Rogers et al., 1996), slurry, and solid manure (Eghball and Power, 1999; Schmidt et al., 1994; Evans et al., 1977) compared with inorganic fertilizer N (Bergareche and Simon, 1989) on forage production. For forage quality, most studies have compared the effects of animal waste with only a single rate of inorganic fertilizer N (Min et

A. Adeli and D.E. Rowe, USDA-ARS, Waste Manage. and Forage Res. Unit, 810 Hwy. 12 East, Mississippi State, MS 39762; J.J. Varco, Dep. of Plant and Soil Sci., Mississippi State Univ., Mississippi State, MS 39762; and K.R. Sistani, USDA-ARS, Waste Manage. Unit, 230 Bennett Ln., Bowling Green, KY 42104. Contribution from the Mississippi Agric. Exp. Stn. Journal Paper no. J10313. Received 19 Feb. 2004. *Corresponding author (aadeli@msa-msstate.ars.usda.gov).

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677 S. Segoe Rd., Madison, WI 53711 USA

Abbreviations: ADF, acid detergent fiber; CP, crude protein; IVTD, in vitro true digestibility; NDF, neutral detergent fiber.

al., 2002) or in combination with fertilizer (Schmidt et al., 1994). Relatively little work has been done involving the effects of swine lagoon effluent relative to commercial fertilizer at equivalent rates on forage quality components. Thus, the objective of this study was to determine the effects of equivalent swine lagoon effluent and commercial fertilizer application rates and harvest date on dry matter yield and nutritive value of bermudagrass and johnsongrass.

MATERIALS AND METHODS

Soil Characteristics and Experimental Design

Studies were conducted for 2 yr on a commercial swine facility located near Brooksville, MS. Soils were an alkaline Okolona silty clay (fine, montmorillonitic, thermic, Typic Chromudert) and an acid Vaiden silty clay (very fine, montmorillonitic, thermic, Vertic Hapludalf). Initial soil samples were taken from each site at 0- to 15-cm depth and analyzed for physical and chemical characteristics. Soil textural analysis was determined by the hydrometer method (Day, 1965); organic matter was determined by the acid dichromate digestion method (Peech et al., 1974); and pH was determined in a 1:1 soil/water suspension. Both soils are representative of the Blackland Prairie major land resources area and initially tested very low (Vaiden) to low (Okolona) in P (Table 1).

Annual swine effluent and corresponding N, P, and K application rates defined as control, low, medium, and high are presented in Table 2. At each site, a randomized complete block design with a factorial arrangement of treatments replicated four times was used. Treatments were multiple effluent irrigations resulting in four N rates from 0 to 665 kg N ha^{-1} yr^{-1}. In each block, for comparison purposes, commercial fertilizer (N, P, and K) treatments were applied to additional plots at rates equivalent to swine effluent rates. Commercial fertilizer sources were ammonium nitrate (34–0–0), concentrated superphosphate (0–46–0), and muriate of potash (0–0–60). Individual plot dimensions were 3.66 by 3.66 m with 3.05-m alleys.

Grass Establishment, Maintenance, and Harvesting Date

Johnsongrass was naturally established on the Okolona site. However, hybrid ‘Alicia’ bermudagrass was planted on the Vaiden site by sprigging, at the rate of 3.0 Mg ha^{-1}, on 25 May 1995. Clippings were spread, disked immediately after spreading, and cultipacked. Plots were irrigated with fresh water every day until the bermudagrass was established. In 1996, for both grasses, Weedmaster {BASF Corp., Research Triangle Park, NC; active ingredients: dicambia (3,6-dichloro-2-methoxybenzoic acid) and 2,4-D [(2,4-dichlorophenoxy)acetic acid]} was applied during April at the rate of 0.28 kg dicamba ha^{-1} and 0.80 kg 2,4-D ha^{-1}. Winter growth was mowed and removed from all plots in early May in 1995 and 1996 for johnsongrass and in 1996 for bermudagrass.

Experiments were completely independent of each other. Since these grasses were grown on two different soil types, the responses of grass species to swine effluent were not compared with each other but were evaluated separately. The subject of this study was two separate trials, a bermudagrass trial and a johnsongrass trial.

Forage grasses were harvested after completing each incremental treatment application (either 2.5 or 5 cm ha^{-1}), allowing at least 21 d of growth for bermudagrass and growth to the boot stage for johnsongrass. During the establishment year for bermudagrass, only one harvest was taken, on 7 Aug. 1995. Cutting dates for johnsongrass were 18 June, 22 July, and 26 August in 1995. In 1996, the harvesting dates were 6 June, 2 July, and 6 August for bermudagrass and 17 June, 18 July, and 19 August for johnsongrass. Two swaths (total of 2.77 m^2) were harvested from each plot using a commercial rotary mower set at a height of 5 cm. Harvested forage was weighed, and yield was recorded. In each harvest, forage samples (500-g wet weight) were taken from each plot and sealed in plastic bags for nutrient analysis. Forage samples were dried at 65°C for 72 h in a forced-air oven and then ground in a Wiley mill to pass a 2-mm sieve for nutrient analysis. The amount of precipitation in each rain event and the daily ambient temperature were received from Brooksville Experiment Station, Mississippi State University facilities. The magnitude of rainfall

Table 1. Initial chemical and physical characteristics of the Vaiden and Okolona soils used in the study.

Parameter	Vaiden	Okolona
pH	5.5	7.3
Organic matter, g kg^{-1}	21.0	26.0
Total N, g kg^{-1}	1.5	1.8
MSTP, kg ha^{-1}†	15.0	21.0
CEC, cmol$_c$ kg^{-1}‡	15	24
K, mg kg^{-1}	102.0	132.0
$CaCO_3$, g kg^{-1}	22.0	480.0
Mg, mg kg^{-1}	160.0	144.0
Sand, %	12	10
Silt, %	45	40
Clay, %	54	50
Texture	Silty clay	Silty clay

† MSTP, Mississippi soil test P (Pettiet, 1973).
‡ CEC, cation exchange capacity.

Table 2. Annual N, P, and K rates supplied by effluent and commercial fertilizer applied to bermudagrass and johnsongrass.†

	1995						1996					
	Effluent			Fertilizer			Effluent			Fertilizer		
Treatment	N	P	K	N	P	K	N	P	K	N	P	K
	kg ha^{-1}											
	Bermudagrass											
Low	115	17	110	112	14	112	236	30	227	224	28	224
Medium	224	33	220	224	28	224	452	62	455	448	56	448
High	328	46	329	336	42	336	667	90	686	672	84	672
	Johnsongrass											
Low	236	30	218	224	28	224	234	30	227	224	28	224
Medium	443	60	446	448	56	448	453	62	455	448	56	448
High	665	90	668	672	84	672	665	91	682	672	84	672

† In each site, commercial fertilizer N, P, and K were applied at rates approximately equivalent to effluent N, P, and K rates.

Table 3. Precipitation and temperatures for 1995 and 1996 growing seasons at the study site.

Year/month	Avg. high temperature	Precipitation
	°C	mm
1995		
March	20.7	163
April	25.2	195
May	28.8	95
June	34.0	98
July	34.0	89
August	33.3	154
September	30.1	32
1996		
March	16.4	146
April	23.4	110
May	29.8	80
June	31.2	87
July	36.6	65
August	32.3	94
September	29.1	96

and the ambient temperature for the growing season are shown in Table 3.

Swine Effluent Irrigation and Sampling

The source of swine effluent for irrigation was an anaerobic lagoon at a farrow to finish swine operation. Due to the establishment of bermudagrass on Vaiden soil in 1995, the annual swine lagoon effluent application rates in 1995 were 0, 2.5, 5, and 7.5 cm ha^{-1} for Vaiden site while the rates were doubled on the Okolona site. In 1996, the annual swine effluent application rates were 0, 5, 10, and 15 cm ha^{-1} for both sites. Swine effluent was applied in 0.64 cm ha^{-1} increments up to 2.5 cm ha^{-1} in a given day. Irrigation was repeated until each incremental rate was achieved (i.e., 5, 10, and 15 cm ha^{-1}), at which time irrigation was stopped to allow the forage adequate time to grow and for a hay harvest (Table 4). For each effluent irrigation event, 0.64 cm ha^{-1} of fresh water was applied to check and fertilized plots to dissolve the commercial fertilizer and to facilitate its incorporation into the soil. A 1500-L water wagon tank was used for delivery of irrigation water and swine lagoon effluent. Swine lagoon effluent was applied to the plots using a garden hose attached to the tank with a small pump equipped with a pressure gauge to keep the flow constant. Based on the area of the plot (12.96 m^2), for each irrigation event (0.64 cm ha^{-1}), it was calculated that 84 L of swine effluent was needed to be applied per plot. To monitor nutrient content of swine effluent, effluent samples were obtained from each tank full. Samples were stored on ice before transport to the laboratory.

In 1995, irrigation with swine effluent was initiated on 10 May and continued until 28 July for johnsongrass. For bermudagrass, irrigation was started on 28 June and continued until 16 July. In 1996, irrigation with swine effluent started on 10 May and 12 May and ended on 8 July and 21 July for bermudagrass and johnsongrass, respectively.

Table 5. Average analysis of swine effluent used in irrigation.

Parameter	1995	1996
pH	7.8	7.9
Total N, mg L^{-1}	411	442
NH_4^+–N, mg L^{-1}	339	388
Total P, mg L^{-1}	63	61
K, mg L^{-1}	396	475
Ca, mg L^{-1}	88	59
Mg, mg L^{-1}	48	22
TSS, g L^{-1}†	2.8	3.0

† TSS, total suspended solids.

Laboratory Analyses

Effluent pH was determined after allowing subsamples to warm to room temperature, with the remainder of each sample preserved by acidifying to a pH < 2 (2 mL H_2SO_4 L^{-1}) and subsequently frozen until analysis (Greenberg et al., 1992). Effluent samples were analyzed for total N using a modified micro-Kjeldahl procedure described by Nelson and Sommers (1973). The digest was analyzed using a phenol-hypochlorite colorimetric assay (Cataldo et al., 1974). Total inorganic N ($NH_4 + NO_3$) of the effluent was analyzed using steam distillation (Bremner and Keeney, 1965). Total P was analyzed using a H_2SO_4–HNO_3 acid digestion procedure (Greenberg et al., 1992), and the digest was analyzed for P using a colorimetric assay developed by Murphy and Riley (1962). Total K, Ca, and Mg of the effluent acid digest were determined using atomic absorption spectrophotometry. Swine effluent samples were obtained from each irrigation event, analyzed, and the average for each parameter is shown in Table 5.

Total N concentration of the forage samples was determined by combustion using an automated dry combustion analyzer (Model NA 1500 NC, Carlo Erba, Milan, Italy), and CP was calculated as N $\times$ 6.25 (AOAC, 1990). The ADF and NDF were measured by the method of Goering and Van Soest (1970). In vitro true digestibility was determined using the two-stage technique of Tilley and Terry (1963). Nitrate N in forage samples was determined colorimetrically according to the method adapted to plants by Wooley et al. (1960).

Statistical Analysis

All data were analyzed using the PROC MIXED procedure of SAS (Littell et al., 1996). Effects of source, fertilization

Table 4. Irrigation and harvest schedule for 1995 and 1996. Each irrigation event supplied 5 cm swine effluent ha^{-1}.

	1995			1996		
Irrigation event†	Cumulative application	Irrigation date	Harvest date‡	Cumulative application	Irrigation date	Harvest date
	cm ha^{-1}			cm ha^{-1}		
			Bermudagrass§			
First	2.5	28 June–5 July	7 August	5	10–14 May	5 June
Second	5	7 July–11 July	–	10	6–10 June	2 July
Third	7.5	13 July–16 July	–	15	3–8 July	1 August
			Johnsongrass			
First	5	10–19 May	18 June	5	12–18 May	17 June
Second	10	19–24 June	22 July	10	18–21 June	18 July
Third	15	23–28 July	26 August	15	19–21 July	19 August

† First effluent treatment = 5 cm ha^{-1}, second effluent treatment = (first + 5 cm ha^{-1} = 10 cm ha^{-1}), and third effluent treatment = (second + 5 cm ha^{-1} = 15 cm ha^{-1}).
‡ Due to grass establishment, bermudagrass was harvested only one time, and application rates were 0, 2.5, 5, and 7.5 cm ha^{-1}.
§ Bermudagrass and johnsongrass were evaluated on different soil types and not statistically compared.

Table 6. Analysis of variance significance levels for the effect of source, fertilization rate, and harvest date on dry matter yield and nutritive values of bermudagrass and johnsongrass.

	Bermudagrass						Johnsongrass					
	Yield	NO_3–N	CP†	NDF‡	ADF§	IVTD¶	Yield	NO_3–N	CP	NDF	ADF	IVTD
Source (S)	NS	*	NS#	NS	NS	NS	NS	*	*	NS	NS	NS
Fertilization rate (R)	**	*	*	*	NS	*	*	**	*	*	*	*
Harvest date (H)	*	*	*	*	*	*	*	*	*	*	*	*
S × R	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
S × H	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
R × H	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
S × R × H	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Year (Y)	*	*	*	*	*	*	*	*	*	*	*	*
S × Y	NS	*	NS	NS	NS	NS	NS	*	NS	NS	NS	NS
R × Y	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
H × Y	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
S × R × Y	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
S × H × Y	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	NS
R × H × Y	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
S × R × H × Y	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS

* Significant at the 0.05 level of probability.
** Significant at the 0.01 level of probability.
† CP, crude protein.
‡ NDF, neutral detergent fiber.
§ ADF, acid detergent fiber.
¶ IVTD, in vitro true digestibility.
\# NS, not significant.

rate, and harvest date on dry matter yield and nutritive values of bermudagrass and johnsongrass, including CP, NDF, ADF, IVTD, and NO_3–N levels, were evaluated with analysis of variance for a randomized complete block design with a factorial arrangement of treatments (Table 6). Fertilization rate, fertilizer source, and harvest date were fixed variables, whereas field replicate ($n = 4$) was the random variable. Therefore, for each grass, each main effect (source, fertilization rate, harvest date,

Table 7. Dry matter yield of grasses as affected by nutrient source, fertilization rate, and harvest date.

Source	Rate	1995 Harvest date			1995 Rate mean	1996 Harvest date			1996 Rate mean	Overall rate effect†
		Johnsongrass								
		28 June	11 Aug.	28 Sept.		17 June	18 July	19 Aug.		
		Mg ha^{-1}								
Fertilizer	Control	1.1^{b}‡	1.4^{c}	0.6^{c}	3.1^{c}	0.9^{b}	1.1^{c}	0.7^{b}	2.7^{b}	2.7^{c}
	Low	$2.5^{a,l}$§	$3.8^{b,m}$	$2.1^{b,l}$	8.4^{b}	$2.1^{a,m}$	$2.3^{b,m}$	$1.5^{a,l}$	5.9^{b}	6.1^{b}
	Medium	$2.5^{a,l}$	$4.9^{a,n}$	$3.5^{a,m}$	10.9^{a}	$2.3^{a,l}$	$3.5^{a,m}$	$2.1^{a,l}$	7.9^{a}	8.3^{a}
	High	$2.5^{a,l}$	$4.6^{a,n}$	$3.4^{a,m}$	10.5^{a}	$2.4^{a,l}$	$3.2^{a,m}$	$2.1^{a,l}$	7.7^{a}	8.1^{a}
Harvest mean		2.2^{l}	3.8^{m}	2.4^{l}		1.9^{l}	2.5^{m}	1.6^{l}		
Effluent										
	Control	1.1^{b}	1.4^{c}	0.6^{c}	3.1^{c}	0.9^{b}	1.1^{c}	0.7^{c}	2.7^{b}	
	Low	$2.6^{a,l}$	$3.8^{b,m}$	$2.0^{b,l}$	8.4^{b}	$2.2^{a,m}$	$2.4^{b,m}$	$1.7^{b,l}$	6.3^{b}	
	Medium	$2.6^{a,l}$	$4.7^{a,n}$	$3.3^{a,m}$	10.6^{a}	$2.4^{a,l}$	$3.9^{a,m}$	$2.4^{a,l}$	8.7^{a}	
	High	$2.6^{a,l}$	$4.7^{a,n}$	$3.3^{a,m}$	10.6^{a}	$2.4^{a,l}$	$3.9^{a,m}$	$2.2^{a,l}$	8.5^{a}	
Harvest mean		2.2^{l}	3.7^{m}	2.3^{l}		2.0^{l}	2.8^{m}	1.8^{l}		
Averaged over source		2.2^{l}	3.8^{m}	2.4^{l}		2.0^{l}	2.7^{m}	1.7^{l}		
Overall effect of harvest date¶		2.1^{l}	3.3^{m}	2.1^{l}						
		Bermudagrass								
		–	7 Aug.	–	–	6 June	2 July	6 Aug.		
		Mg ha^{-1}								
Fertilizer	Control	–	1.6^{c}	–	–	0.5^{c}	0.7^{c}	0.4^{d}	1.6^{c}	1.6^{c}
	Low	–	3.6^{b}	–	–	$1.9^{a,l}$	$2.5^{b,m}$	$1.5^{c,l}$	5.9^{b}	6.1^{b}
	Medium	–	3.8^{ab}	–	–	$1.8^{ab,l}$	$3.2^{a,n}$	$2.7^{b,m}$	7.7^{a}	8.0^{a}
	High	–	3.8^{ab}	–	–	$1.7^{b,l}$	$3.5^{a,m}$	$3.2^{a,m}$	8.4^{a}	8.5^{a}
Harvest mean			3.2			1.5^{l}	2.5^{m}	2.0^{l}		
Effluent										
	Control	–	1.6^{c}	–	–	0.5^{c}	0.7^{c}	0.4^{d}	1.6^{c}	
	Low	–	3.6^{b}	–	–	$1.9^{a,l}$	$2.6^{b,m}$	$1.7^{c,l}$	6.2^{b}	
	Medium	–	4.0^{ab}	–	–	$1.8^{ab,l}$	$3.5^{a,n}$	$2.9^{ab,m}$	8.2^{a}	
	High	–	4.1^{a}	–	–	$1.9^{a,l}$	$3.5^{a,m}$	$3.2^{a,m}$	8.6^{a}	
Harvest mean		–	3.3	–	–	1.5^{l}	2.6^{m}	2.1^{l}		
Overall effect of harvest date¶			3.3			1.5^{l}	2.5^{m}	2.0^{l}		

† Contrasts testing the effect of application rate across all harvest dates, source, and year: quadratic ($P < 0.05$).
‡ Within a column, means followed by a different superscript letter–a, b, c, or d–differ at $P < 0.05$.
§ Within a row, means followed by a different superscript letter–l, m, or n–differ at $P < 0.05$.
¶ Contrasts testing the effect of harvest date across application rates and sources: quadratic ($P < 0.05$).

and year) and subsequent interactions were evaluated. Least squares means were calculated and separated using Fisher's LSD (Steel and Torrie, 1980) by SAS (SAS Inst., 1996), and polynomial orthogonal contrasts were conducted to evaluate the linearity of effects of fertilization rate and harvest date.

RESULTS AND DISCUSSION

Dry Matter Yield

For both bermudagrass and johnsongrass, variation in dry matter yield was observed between years as a result of nutrient source, fertilization rate, and harvest dates evaluated (Table 7). Average total dry matter yield for bermudagrass for 1996 was 56% ($P < 0.05$) more than 1995, the establishment year for bermudagrass. Average total dry matter yield for johnsongrass for 1995 was 24% more than 1996. A decline in johnsongrass yield from 1995 to 1996 may be related to a noticeably thinner stand caused by intensive hay cutting (Watson et al., 1970). The response pattern of forage growth to fertilization with swine lagoon effluent and commercial fertilizer was similar for both growing seasons. For both grasses, total dry matter yield increased quadratically with increasing swine effluent and commercial fertilizer application rates. Averaged across harvest dates and source for bermudagrass and johnsongrass, total dry matter yield was 1.6 and 2.7 Mg ha^{-1} for control, whereas peak dry matter yields were 8.0 and 8.3 Mg ha^{-1}, which occurred with the application of either swine effluent or commercial fertilizer at the medium rate, respectively (Table 7). Thereafter, forage dry matter yield did not respond to higher levels of fertilization. It appears that application of swine effluent or commercial fertilizer should not exceed the medium rate tested (approximately 450 kg N ha^{-1}). This is in agreement with work by Eichhorn (1989), who obtained a maximum dry matter yield for bermudagrass of 9.5 Mg ha^{-1} with a rate of 448 kg ha^{-1} fertilizer N. Prine and Burton (1956) reported maximum forage yield of bermudagrass when 267 kg N ha^{-1} was applied for the entire growing season during a dry year and with 534 kg N ha^{-1} during a wet year. For both grasses, no significant difference in total dry matter yield was obtained between equivalent swine lagoon effluent and commercial fertilizer applications in 1995 and 1996, suggesting both nutrient sources were similar in nutrient availability at the rates used in this study (Table 7).

Averaged across fertilization rates, a quadratic pattern ($P < 0.05$) was observed for bermudagrass and johnsongrass dry matter yield across the harvest season

Table 8. Nitrate N (NO_3–N) concentration of grasses as affected by nutrient source, fertilization rate, and harvest date.

Source	Rate	1995 Harvest date			1995 Rate mean	1996 Harvest date			1996 Rate mean	Average over year	Overall rate effect†
		Johnsongrass									
		28 June	11 Aug.	28 Sept.		17 June	18 July	19 Aug.			
		μg g^{-1}									
Fertilizer	Control	173^{d}‡	176^{d}	186^{d}	178^{d}	172^{d}	185^{d}	209^{d}	189^{d}	184^{d}	184^{d}
	Low	368^{c}	371^{c}	423^{c}	387^{c}	569^{c}	643^{c}	849^{c}	687^{c}	537^{c}	518^{c}
	Medium	1156^{b}	1164^{b}	1263^{b}	1194^{b}	1334^{b}	1544^{b}	1612^{b}	1497^{b}	1346^{b}	1316^{b}
	High	1241^{a}	1514^{a}	1695^{a}	1483^{a}	1644^{a}	1820^{a}	2065^{a}	1843^{a}	1663^{a}	1626^{a}
Harvest mean		735^{l}§	806^{m}	891^{n}		930^{l}	1048^{m}	1184^{n}			
Effluent											
	Control	173^{d}	176^{d}	186^{d}	178^{d}	172^{d}	185^{d}	209^{d}	189^{d}	184^{d}	
	Low	354^{c}	362^{c}	599^{c}	438^{c}	537^{c}	307^{c}	838^{c}	560^{c}	499^{c}	
	Medium	1167^{b}	1178^{b}	1252^{b}	1199^{b}	1314^{b}	1208^{b}	1594^{b}	1373^{b}	1286^{b}	
	High	1220^{b}	1508^{a}	1679^{a}	1469^{a}	1626^{a}	1479^{a}	2021^{a}	1709^{a}	1589^{a}	
Harvest mean		729^{l}	806^{m}	929^{n}		912^{m}	795^{l}	1166^{n}			
Averaged over source		732^{l}	806^{m}	910^{n}		921^{l}	922^{l}	1175^{m}			
Overall effect of harvest date¶		826^{l}	864^{m}	1043^{n}							
		Bermudagrass									
			7 Aug.			6 June	2 July	6 Aug.			
		μg g^{-1}									
Fertilizer	Control	–	159^{d}	–	–	215^{c}	230^{g}	241^{d}	229^{d}	194^{d}	194^{d}
	Low	–	678^{c}	–	–	781^{b,l}	860^{e,m}	1008^{c,n}	883^{c}	781^{c}	750^{c}
	Medium	–	1529^{b}	–	–	1794^{a,l}	1816^{c,m}	2011^{b,n}	1874^{b}	1702^{b}	1669^{b}
	High	–	1905^{a}	–	–	1903^{a,l}	2261^{a,m}	2445^{a,n}	2203^{a}	2054^{a}	2028^{a}
Harvest mean		–	1068	–	–	1173^{l}	1292^{m}	1426^{n}			
Effluent											
	Control	–	159^{d}	–	–	215^{c}	230^{g}	241^{d}	229^{d}	194^{d}	
	Low	–	671^{c}	–	–	763^{b,m}	544^{f,l}	984^{c,n}	764^{c}	718^{c}	
	Medium	–	1513^{b}	–	–	1777^{a,m}	1501^{d,l}	1990^{b,n}	1756^{b}	1635^{b}	
	High	–	1899^{a}	–	–	1885^{a,l}	2002^{b,m}	2422^{a,n}	2103^{a}	2001^{a}	
Harvest mean		–	1061	–	–	1160^{m}	1069^{l}	1409^{n}			
Overall effect of harvest date¶		–	1065	–	–	1167^{l}	1181^{l}	1418^{m}			

† Contrasts testing the effect of application rate across all harvest dates, year, and source: linear ($P < 0.05$).
‡ Within a column, means followed by a different superscript letter–a, b, c, d, e, f, or g–differ at $P < 0.05$.
§ Within a row, means followed by a different superscript letter–l, m, or n–differ at $P < 0.05$.
¶ Contrasts testing the effect of harvest date across application rates and sources: linear ($P < 0.05$).

(Table 7). For example, for both grasses, dry matter yield peaked in the July harvest and then decreased with later harvests. This is in agreement with research by Chambliss et al. (1999) and Mislevy (1999), who reported that peak dry matter production for bermudagrass and stargrass (*Cynodon nlemfuensis* Vanderyst) occurred during midsummer. Regardless of the nutrient source, a threshold existed at which additional N fertilization did not improve yield. Due to shorter day effect (Osborne et al., 1999), additional N applied late in the growing season may not improve forage dry matter yield and may increase the potential contamination of surface and ground waters through runoff or leaching.

Nitrate Nitrogen Concentration

For bermudagrass and johnsongrass, averaged across harvest dates, NO_3–N concentration was related to N supply and accumulated linearly with increasing swine effluent and commercial fertilizer application rates in 1995 and 1996 (Table 8). These findings are similar to the results reported in other studies in which N fertilization increased nitrate concentrations in warm-season grasses (Bergareche and Simon, 1989; Wilman and Wright, 1986). No significant differences in NO_3–N concentration were obtained between equivalent swine effluent and commercial fertilizer application rates, except for the July harvest in 1996 in which NO_3–N concentrations in both grasses were significantly lower for swine effluent than commercial fertilizer applications (Table 8). This is possibly due to greater potential for NH_3 volatilization from surface-applied swine effluent in the hot month of July 1996 (Table 1). Klausner and Guest (1981) reported that hot and dry weather conditions accelerate NH_3 volatilization. Averaged across fertilization rates, a linear increase ($P < 0.05$) was observed for NO_3–N concentration in bermudagrass and johnsongrass across the harvest season.

Crude Protein

Averaged across harvest dates, CP for bermudagrass and johnsongrass reached a plateau with application of approximately 450 kg N ha^{-1} from either swine effluent or commercial fertilizer (Table 9). No significant difference in CP concentration of bermudagrass was obtained between equivalent swine lagoon effluent and commercial fertilizer applications, suggesting that both sources were similar in availability of N for bermudagrass. Only at the high rate was CP concentration of bermudagrass 7% lower for swine effluent than commercial fertilizer in 1996 (Table 9). In 1995, the establishment year for

Table 9. Crude protein content of grasses as affected by nutrient source, fertilization rate, and harvest date.

Source	Rate	1995 Harvest date			1995 Rate mean	1996 Harvest date			1996 Rate mean	Averaged over year	Overall rate effect†
		Johnsongrass									
		28 June	11 Aug.	28 Sept.		17 June	18 July	19 Aug.			
		g kg^{-1}									
Fertilizer	Control	83^{e}‡	106^{d}	89^{g}	93^{f}	119^{e}	128^{f}	94^{g}	114^{f}	104^{e}	104^{c}
	Low	93^{d}	122^{c}	119^{e}	111^{e}	173^{b}	174^{b}	149^{c}	165^{b}	138^{c}	131^{b}
	Medium	134^{a}	143^{a}	138^{b}	138^{b}	181^{a}	183^{a}	158^{b}	174^{a}	156^{a}	148^{a}
	High	137^{a}	147^{a}	146^{a}	143^{a}	176^{b}	185^{a}	163^{a}	175^{a}	159^{a}	149^{a}
Harvest mean		112^{l}§	130^{m}	123^{l}		162^{m}	168^{n}	141^{l}			
Effluent											
	Control	83^{e}	106^{d}	89^{g}	93^{f}	119^{e}	128^{f}	94^{g}	114^{f}	104^{e}	
	Low	96^{d}	124^{c}	114^{f}	111^{e}	143^{d}	145^{e}	114^{f}	134^{e}	123^{d}	
	Medium	129^{b}	137^{b}	129^{c}	132^{c}	143^{d}	159^{d}	137^{e}	146^{d}	139^{b}	
	High	120^{c}	131^{c}	123^{d}	125^{d}	148^{c}	165^{c}	143^{d}	152^{c}	139^{b}	
Harvest mean		107^{l}	125^{n}	114^{m}		138^{m}	149^{n}	122^{l}			
Averaged over source		110^{l}	128^{n}	119^{m}		150^{m}	159^{n}	132^{l}			
Overall effect of harvest date¶		130^{l}	144^{m}	126^{l}							
		Bermudagrass									
			7 Aug.			6 June	2 July	6 Aug.			
		g kg^{-1}									
Fertilizer	Control	–	75^{f}	–	–	114^{e,m}	146^{e,n}	92^{f,l}	117^{d}	96^{d}	94^{c}
	Low	–	131^{d}	–	–	168^{d,l}	177^{d,m}	169^{d,l}	171^{c}	151^{c}	148^{b}
	Medium	–	167^{b}	–	–	206^{a}	207^{a}	201^{a}	205^{a}	186^{a}	183^{a}
	High	–	172^{a}	–	–	211^{a,m}	200^{b,l}	198^{ab,l}	203^{a}	188^{a}	183^{a}
Harvest mean		–	136	–	–	171^{m}	183^{n}	165^{l}			
Effluent											
	Control	–	75^{f}	–	–	114^{e,m}	146^{d,n}	92^{f,l}	117^{d}	92^{d}	
	Low	–	121^{e}	–	–	174^{c,m}	178^{d,m}	156^{e,l}	169^{c}	147^{c}	
	Medium	–	158^{c}	–	–	208^{a,m}	201^{b,l}	196^{b,l}	202^{a}	180^{b}	
	High	–	166^{b}	–	–	194^{b,m}	194^{c,m}	181^{c,l}	190^{b}	178^{b}	
Harvest mean		–	130	–	–	173^{m}	180^{n}	156^{l}			
Overall effect of harvest date¶		–	133	–	–	172^{m}	182^{n}	161^{l}			

† Contrasts testing the effect of application rate across all harvest dates, year, and source: quadratic ($P < 0.05$).
‡ Within a column, means followed by a different superscript letter–a, b, c, d, e, f, or g–differ at $P < 0.05$.
§ Within a row, means followed by a different superscript letter–l, m, or n–differ at $P < 0.05$.
¶ Contrasts testing the effect of harvest date across application rates, sources and year: quadratic ($P < 0.05$).

bermudagrass, the CP concentration was 5% lower for swine effluent than commercial fertilizer. Averaged across harvest dates, the CP concentration of johnsongrass was 7 and 16% lower ($P < 0.05$) for swine effluent than commercial fertilizer in 1995 and 1996, respectively (Table 9). Since johnsongrass was naturally established in an Okolona soil, lower CP concentration of johnsongrass for swine effluent than commercial fertilizer could be related to NH_3 volatilization, which may have been greater from Okolona soil than Vaiden soil due to an alkaline pH (Hoff et al., 1981). For both grasses, the plateau response of CP concentrations to swine effluent and commercial fertilizer applications is in agreement with the work by Harvey et al. (1996), who reported that CP concentration of bermudagrass increased only slightly when N rate from swine effluent application was increased from 456 to 873 kg ha^{-1}.

Averaged across fertilization rates, a quadratic pattern ($P < 0.05$) was observed for CP concentration in bermudagrass and johnsongrass across the harvest season (Table 9). For example, the CP concentration of both grasses peaked in the July harvest and then declined with later harvests. For both grasses, the lowest magnitude for CP concentration was obtained for the August harvest. Environmentally and nutritionally, it is important to maximize the utilization and assimilation of applied N. Thus, applying swine effluent early in the growing season appears to be a better practice than applying it late in the season, possibly because more active early-season plant growth results in greater utilization and assimilation of swine effluent N. These findings are similar to the results reported by Anderson et al. (1993), in which dairy slurry N was utilized more by warm-season grasses from early- than late-summer application.

Neutral Detergent Fiber and Acid Detergent Fiber

Averaged across harvest dates, a quadratic pattern ($P < 0.05$) was observed for NDF and ADF concentrations in bermudagrass and johnsongrass across the fertilization rates (Tables 10 and 11). For example, the peak NDF and ADF concentrations for bermudagrass (568 and 376 g kg^{-1}) and johnsongrass (666 and 405 g kg^{-1}) occurred at the low application rate (approximately 230 kg N ha^{-1}) and then declined with increasing swine effluent and commercial fertilizer application rates. No significant differences in the NDF and ADF concentrations of bermudagrass and johnsongrass were obtained between equivalent swine lagoon effluent and commer-

Table 10. Neutral detergent fiber content of grasses as affected by nutrient source, fertilization rate, and harvest date.

Source	Rate	1995 Harvest date			1995 Rate mean	1996 Harvest date			1996 Rate mean	Averaged over year	Overall rate effect†
		Johnsongrass									
		28 June	11 Aug.	28 Sept.		17 June	18 July	19 Aug.			
		g kg^{-1}									
Fertilizer	Control	653^{c}‡	689^{b}	655^{c}	666^{b}	635^{b}	651^{c}	633^{b}	640^{b}	653^{b}	653^{b}
	Low	669^{a}	702^{a}	679^{a}	683^{a}	640^{a}	667^{a}	649^{a}	652^{a}	668^{a}	666^{a}
	Medium	636^{d}	678^{c}	640^{e}	651^{c}	626^{d}	649^{c}	632^{b}	636^{b}	644^{c}	645^{c}
	High	625^{e}	668^{d}	627^{g}	640^{d}	625^{d}	641^{d}	620^{c}	629^{c}	635^{d}	635^{d}
Harvest mean		646^{l}§	684^{m}	650^{l}		632^{l}	652^{m}	634^{l}			
Effluent											
	Control	653^{c}	689^{b}	655^{c}	666^{b}	635^{b}	651^{c}	633^{b}	640^{b}	653^{b}	
	Low	664^{b}	698^{a}	672^{b}	678^{a}	641^{a}	660^{b}	646^{a}	649^{a}	664^{a}	
	Medium	632^{d}	672^{d}	646^{d}	650^{c}	632^{bc}	652^{c}	632^{b}	639^{b}	645^{c}	
	High	623^{e}	659^{e}	632^{f}	638^{d}	629^{dc}	644^{d}	624^{c}	632^{c}	635^{d}	
Harvest mean		643^{l}	680^{n}	651^{m}		634^{l}	652^{m}	634^{l}			
Averaged over source		645^{l}	682^{n}	651^{m}		633^{l}	652^{m}	634^{l}			
Overall effect of harvest¶		639^{l}	667^{m}	643^{l}							
		Bermudagrass									
			7 Aug.			6 June	2 July	6 Aug.			
		g kg^{-1}									
Fertilizer	Control	–	545^{c}	–	–	$530^{c,m}$	$597^{b,n}$	$534^{b,l}$	554^{c}	550^{c}	550^{b}
	Low	–	563^{a}	–	–	$553^{a,l}$	$606^{a,n}$	$583^{a,m}$	581^{a}	572^{a}	568^{a}
	Medium	–	531^{e}	–	–	$518^{d,l}$	$586^{cd,n}$	$525^{c,m}$	543^{d}	537^{d}	539^{c}
	High	–	527^{e}	–	–	$514^{d,l}$	$574^{e,m}$	$513^{d,l}$	534^{e}	531^{e}	530^{d}
Harvest mean		–	541	–	–	529^{l}	591^{n}	539^{m}			
Effluent											
	Control	–	545^{c}	–	–	$530^{c,l}$	$597^{b,m}$	$534^{b,l}$	554^{c}	550^{c}	
	Low	–	553^{b}	–	–	$547^{b,l}$	$589^{c,n}$	$580^{a,m}$	572^{b}	563^{b}	
	Medium	–	538^{d}	–	–	$519^{d,l}$	$582^{d,n}$	$526^{c,m}$	542^{d}	540^{d}	
	High	–	522^{f}	–	–	$514^{d,l}$	$573^{e,m}$	$512^{d,l}$	533^{e}	528^{e}	
Harvest mean		–	540	–	–	528^{l}	585^{n}	538^{m}			
Overall effect of harvest¶		–	541	–	–	529^{l}	588^{n}	539^{m}			

† Contrasts testing the effect of application rate across all harvest dates, year, and source: quadratic ($P < 0.05$).
‡ Within a column, means followed by a different superscript letter–a, b, c, d, e, f, or g–differ at $P < 0.05$.
§ Within a row, means followed by a different superscript letter–l, m, or n–differ at $P < 0.05$.
¶ Contrasts testing the effect of harvest date across application rates, year, and sources: quadratic ($P < 0.05$).

cial fertilizer. In contrast to our results, Rogers et al. (1996) reported that increased N fertilization had little to no effect on the NDF concentration of bermudagrass. The ADF value of our findings are larger than the ADF value of 336 g kg^{-1} for bermudagrass and 358 g kg^{-1} for bahiagrass (*Paspalum notatum* Flüggé) reported by Johnson et al. (2001).

Averaged across fertilization rates, a quadratic pattern ($P < 0.05$) was observed for NDF and ADF concentrations in bermudagrass and johnsongrass across the harvest season (Tables 10 and 11). For example, the NDF and ADF concentrations of both grasses peaked in July, the hottest month during the growing season (Table 1) and then declined with later harvests, indicating that both NDF and ADF concentrations were positively correlated with temperature increases. These results are similar to the work by Henderson and Robinson (1982), who reported that maximum NDF and ADF concentrations for bahiagrass and bermudagrass were obtained when temperatures increased from 26 to 35°C.

In Vitro True Digestibility

Averaged across harvest dates, a quadratic pattern ($P < 0.05$) was observed for IVTD concentrations in bermudagrass and johnsongrass across the fertilization rates (Table 12). In contrast to NDF and ADF concentrations, the IVTD concentrations of bermudagrass and johnsongrass decreased at the low application rate compared with the control and then increased with increasing swine lagoon effluent and commercial fertilizer rates. Henderson and Robinson (1982) reported highly significant negative correlations between digestibility and fiber contents in bermudagrass, stargrass, and bahiagrass. In contrast to our results, Harvey et al. (1996) reported no effect of N fertilization from swine effluent on digestibility of bermudagrass pastures fertilized with either 456 or 873 kg N ha^{-1} annually. No significant differences in the IVTD concentrations of bermudagrass and johnsongrass were obtained between equivalent swine lagoon effluent and commercial fertilizer applications. Averaged across treatments, the IVTD concentrations of bermudagrass and johnsongrass were 483 and 524 g kg^{-1}, respectively (Table 12). These values are lower than the IVTD values of 574 g kg^{-1} in bermudagrass and 599 g kg^{-1} in bahiagrass reported by Johnson et al. (2001).

Averaged across fertilization rates, a quadratic pattern ($P < 0.05$) was observed for IVTD concentrations in bermudagrass and johnsongrass across the harvest season due to shorter day effect (Osborne et al., 1999). For example, the IVTD concentrations of both grasses

Table 11. Acid detergent fiber content of grasses as affected by nutrient source, fertilization rate, and harvest date.

		1995				1996					
Source	Rate	Harvest date			Rate mean	Harvest date			Rate mean	Average over year	Overall rate effect†
		Johnsongrass									
		28 June	11 Aug.	28 Sept.		17 June	18 July	19 Aug.			
		g kg^{-1}									
Fertilizer	Control	428^{a}‡	458^{b}	433^{b}	440^{b}	351^{a}	380^{b}	348^{bc}	360^{a}	400^{b}	400^{b}
	Low	429^{a}	469^{a}	443^{a}	447^{a}	354^{a}	386^{a}	353^{a}	364^{a}	406^{a}	405^{a}
	Medium	411^{b}	434^{c}	415^{c}	420^{d}	347^{b}	375^{c}	344^{cd}	355^{b}	388^{c}	389^{c}
	High	381^{e}	391^{e}	403^{d}	391^{f}	338^{c}	371^{cd}	340de	350^{c}	371^{d}	376^{d}
Harvest mean		412^{l}§	438^{n}	424^{m}		348^{l}	378^{m}	346^{l}			
Effluent											
	Control	428^{a}	458^{b}	433^{b}	440^{b}	351^{a}	380^{b}	348^{bc}	360^{a}	400^{b}	
	Low	426^{a}	466^{a}	440^{a}	444^{a}	353^{a}	384^{ab}	352^{ab}	363^{a}	404^{a}	
	Medium	403^{c}	461^{b}	416^{c}	427^{c}	345^{b}	372^{cd}	342^{ed}	353^{b}	390^{c}	
	High	396^{d}	428^{d}	399^{d}	413^{e}	335^{c}	368^{d}	339^{e}	347^{c}	380^{d}	
Harvest mean		413^{l}	453^{n}	422^{m}		346^{l}	376^{m}	345^{l}			
Averaged over source		413^{l}	446^{n}	423^{m}		347^{l}	377^{m}	346^{l}			
Overall effect of harvest¶		380^{l}	412^{m}	385^{l}							
		Bermudagrass									
			7 Aug.			6 June	2 July	6 Aug.			
		g kg^{-1}									
Fertilizer	Control	–	358^{e}	–	–	324^{bc}	374^{b}	351^{b}	350^{b}	354^{d}	354^{c}
	Low	–	394^{c}	–	–	330^{a}	388^{a}	361^{a}	360^{a}	377^{a}	376^{a}
	Medium	–	383^{d}	–	–	322^{cd}	371^{b}	342^{c}	345^{bc}	364^{c}	367^{b}
	High	–	401^{b}	–	–	316^{e}	368^{c}	336^{d}	340^{c}	370^{b}	370^{b}
Harvest mean		–	384	–	–	323^{l}	375^{n}	348^{m}			
Effluent											
	Control	–	358^{e}	–	–	324^{bc}	374^{b}	351^{b}	350^{b}	354^{d}	
	Low	–	391^{c}	–	–	328^{ab}	384^{a}	359^{a}	357^{a}	374^{a}	
	Medium	–	390^{c}	–	–	321^{cde}	373^{b}	348^{b}	347^{b}	369^{b}	
	High	–	411^{a}	–	–	318de	361^{d}	338^{d}	339^{c}	370^{b}	
Harvest mean		–	388	–	–	323^{l}	373^{n}	349^{m}			
Overall effect of harvest¶		–	386	–	–	323^{l}	374^{n}	349^{m}			

† Contrasts testing the effect of application rate across all harvest dates, year, and source: quadratic ($P < 0.05$).
‡ Within a column, means followed by a different superscript letter–a, b, c, d, or e–differ at $P < 0.05$.
§ Within a row, means followed by a different superscript letter–l, m, or n–differ at $P < 0.05$.
¶ Contrasts testing the effect of harvest date across application rates, year, and sources: quadratic ($P < 0.05$).

Table 12. In vitro true digestibility content of grasses as affected by nutrient source, fertilization rate, and harvest date.

Source	Rate	1995 Harvest date			1995 Rate mean	1996 Harvest date			1996 Rate mean	Averaged over year	Overall rate effect†
		Johnsongrass									
		28 June	11 Aug.	28 Sept.		17 June	18 July	19 Aug.			
		g kg^{-1}									
Fertilizer	Control	544^{c}‡	533^{cd}	562^{d}	546^{c}	487^{d}	475^{c}	520^{c}	494^{c}	520^{c}	520^{c}
	Low	533^{e}	525^{e}	547^{f}	535^{d}	480^{e}	468^{d}	508^{d}	485^{d}	510^{d}	511^{d}
	Medium	546^{c}	536^{bc}	568^{c}	550^{b}	498^{bc}	485^{a}	526^{b}	503^{b}	527^{b}	528^{b}
	High	554^{ab}	545^{a}	579^{a}	559^{a}	505^{a}	492^{a}	537^{a}	511^{a}	535^{a}	535^{a}
Harvest mean		544^{m}§	535^{l}	564^{n}		493^{m}	480^{l}	523^{n}			
Effluent											
	Control	544^{c}	533^{cd}	562^{d}	546^{c}	487^{d}	475^{c}	520^{c}	494^{c}	520^{c}	
	Low	538^{d}	529de	553^{e}	540^{d}	477^{e}	466^{d}	510^{d}	484^{d}	512^{d}	
	Medium	552^{b}	538^{b}	573^{b}	556^{a}	493^{c}	482^{b}	527^{b}	501^{b}	529^{b}	
	High	558^{a}	543^{a}	576^{ab}	559^{a}	499^{b}	494^{a}	536^{a}	510^{a}	535^{a}	
Harvest mean		548^{m}	536^{l}	566^{n}		489^{m}	479^{l}	523^{n}			
Averaged over source		546^{m}	536^{l}	565^{n}		491^{m}	480^{l}	523^{n}			
Overall effect of harvest date¶		519^{m}	508^{l}	544^{n}							
		Bermudagrass									
			7 Aug.			6 June	2 July	6 Aug.			
		g kg^{-1}									
Fertilizer	Control	–	482^{c}	–	–	460^{d}	445^{d}	495^{b}	467^{b}	475^{b}	475^{b}
	Low	–	475^{d}	–	–	449^{f}	427^{e}	475^{c}	450^{c}	463^{c}	465^{c}
	Medium	–	496^{b}	–	–	473^{b}	466^{b}	527^{a}	489^{a}	493^{a}	492^{a}
	High	–	498^{b}	–	–	482^{a}	475^{a}	532^{a}	496^{a}	497^{a}	500^{a}
Harvest mean		–	488	–	–	466^{m}	453^{l}	507^{n}			
Effluent											
	Control	–	482^{c}	–	–	460^{d}	445^{d}	495^{b}	467^{b}	475^{b}	
	Low	–	478^{dc}	–	–	454^{e}	428^{e}	481^{c}	454^{c}	466^{c}	
	Medium	–	495^{b}	–	–	467^{c}	460^{c}	531^{a}	491^{a}	493^{a}	
	High	–	504^{a}	–	–	482^{a}	473^{a}	534^{a}	499^{a}	502^{a}	
Harvest mean		–	490	–	–	466^{m}	452^{l}	509^{n}			
Overall effect of harvest date¶		–	489	–	–	466^{m}	453^{l}	508^{n}			

† Contrasts testing the effect of application rate across all harvest dates, year, and source: quadratic ($P < 0.05$).
‡ Within a column, means followed by a different superscript letter–a, b, c, d, e, and f–differ at $P < 0.05$.
§ Within a row, means followed by a different superscript letter–l, m, and n–differ at $P < 0.05$.
¶ Contrasts testing the effect of harvest date across application rates, year, and sources: quadratic ($P < 0.05$).

decreased in July, the hottest month during the growing season (Table 1) and then increased with later harvests (Table 12), indicating that IVTD concentrations were negatively correlated with temperature increases. Rusland et al. (1988) determined a similar digestibility pattern in limpograss [*Hemarthria altissima* (Poir.) Stapf & C.E. Hubb.]. Decreases in digestibility of 7.6% for bermudagrass and 12.9% for bahiagrass have been reported when temperature increased from 26 to 35°C (Johnson et al., 2001). The negative relationship between temperature and digestibility may be caused by a reduction in the leaf/stem ratio and increased proportion of the indigestible fractions because of increased metabolic rates of the plant associated with increased temperatures (Nelson and Volenec, 1995).

CONCLUSIONS

Total dry matter yield and CP concentrations reached a plateau with application of approximately 450 kg N ha^{-1} from either swine effluent or commercial fertilizer to bermudagrass and johnsongrass. Fiber contents peaked at the low fertilization rate and then decreased with increasing swine lagoon effluent and commercial fertilizer rates. An inverse relationship was obtained for forage digestibility in response to fertilization rates. Forage NO_3–N content increased linearly with increasing effluent and commercial fertilizer rates. No significant difference in dry matter yield and forage nutritive value levels was obtained between swine lagoon effluent and commercial fertilizer at equivalent rates, suggesting that both nutrient sources were similar in availability of nutrients at rates used in this study. Similarity in nutrient availability between anaerobic swine lagoon effluent and commercial fertilizer simplifies nutrient management decisions due to the abundance of information available on fertilizer effects on forage grasses. Total dry matter yield, CP, and fiber contents peaked in the July harvest, but grass digestibility decreased in July. Decreases in IVTD concentration of bermudagrass and johnsongrass in the July harvest suggest that supplementation may be an appropriate strategy at a time when forage nutritive value may limit animal performance.

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